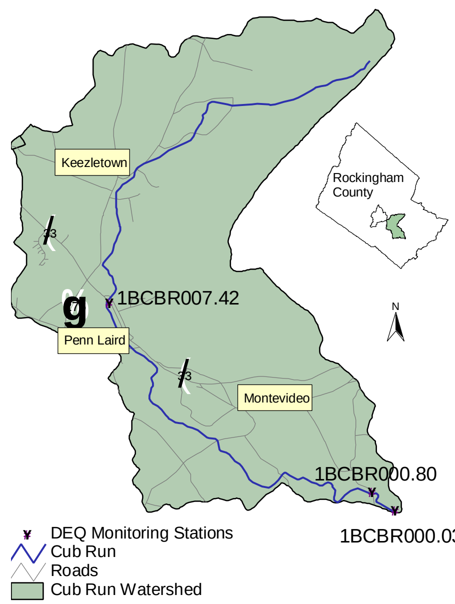
Bacteria Total Maximum Daily Load (TMDL) for Cub Run in Rockingham County, Virginia



Submitted by

Virginia Department of Environmental Quality

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Executive Summary

This report presents the development of a Bacteria Total Maximum Daily Load (TMDL) for the Cub Run watershed. The Cub Run watershed is located in Rockingham County in the Potomac and Shenandoah River Basin (USGS Hydrologic Unit Code 02070005). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Cub Run is VAV-B34R in the Valley region of Virginia.

The impaired segment includes the entire 13.94-mile length of Cub Run, from the headwaters to the confluence with the South Fork of the Shenandoah River.

The Cub Run watershed is approximately 26.8 square miles and encompasses the towns of Keezletown, Penn Laird, and Montevideo, Virginia. The average annual rainfall as recorded at Dale Enterprise, Virginia (~7 miles west of the study area) is 35.23 inches. Landuse in the Cub Run watershed consists primarily of pasture/hay land (46.37%) and forest (45.33%). The remaining 8% of land in the watershed consists primarily of cropland and residential areas. A map of the distribution of land use in the watershed indicates that the forested area of the watershed is mostly confined to the slopes of Massanutten Mountain, while the lower elevations are primarily used for agriculture. The land directly bordering Cub Run (riparian area) is predominantly pasture, with forest in the headwaters and narrow forest buffers along some downstream portions of the stream.

Cub Run was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and the 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria. Out of 18 samples collected from station 1BCBR000.80 during the 1998 assessment period, 5 (or 28%) violated the water quality standard of 1000 cfu/100ml. During the most recent 2002 assessment period, 5 of 23 samples (or 22%) violated the standard.

According to Virginia Water Quality Standards (9 VAC 25-260-10A), "all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."

As indicated above, Cub Run must support all designated uses and meet all applicable criteria. Cub Run does not currently support primary contact recreation.

The load-duration approach was used to develop the TMDL for the Cub Run watershed.

The assessment of bacterial sources involves estimating loads from various sources in the watershed. This assessment was accomplished by determining the relative contribution by these sources using Biological Source Tracking (BST) methodology. A total of 13 ambient water quality samples were collected on a monthly basis from September 2002 through September 2003 for BST analysis. Four categories of sources were considered: human, pet, livestock and wildlife. The analysis determined the relative contribution of all bacteria by these sources. The data indicated that on an average basis, relative contributions of bacteria are - 10% from human sources, 21% from pet sources, 32% from wildlife, and 38% from livestock. Fecal and *E. coli* bacteria were also enumerated as part of the BST analyses.

The bacteria loads in the study watershed were calculated for point sources and non-point sources. The study area has 10 small permitted domestic sewage discharges. The permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100mL) times the permitted flow for each discharge (1000 gal/day) times the appropriate unit conversions. For non-point sources (human, pets, livestock, and wildlife) total annual fecal productions were calculated separately. Data on population density and waste production by septic systems, pets, livestock, and wildlife were collected from various sources, and total fecal productions were calculated with appropriate unit conversions.

The load-duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. A historical flow record was simulated for Cub Run based on a regression of flow in Cub Run to flow in a nearby watershed, where a permanent flow gage was located. From this simulated historical flow record, a flow-duration curve was developed. The load-duration curve was then developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The stream flow from the date of the water quality observation is then used to calculate a stream flow and flow-duration interval for the stream. The loads on the load-duration curve are multiplied by 365 days/year to determine the annual loads. The observed loads were then plotted on the load-duration curve to determine the number and pattern of exceedances of water quality standards. The necessary reductions in bacteria loading were determined by calculating the difference in loads (as a percentage) between the highest water quality exceedance and the maximum allowable load (the TMDL).

The results indicated that the highest exceedance of the water quality standard occurred at a high flow that has been exceeded only 10% of the time (~43 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet the water quality standard. The translated load at this flow condition is 7.61×10^{15} cfu/yr. At the average annual flow condition, this load would be 5.56×10^{15} cfu/yr. To meet the instantaneous *E. coli* standard of 235 cfu/100mL, the average annual load would have to be reduced by 99% to an allowable load of 8.94×10^{13} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions.

For the Cub Run watershed, the average annual *E. coli* load is 5.56×10^{15} cfu/yr, and the TMDL under average annual flow conditions is 6.53×10^{13} cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as computed), and the implicit margin of safety, the load allocation was determined. These values are presented in Table E1.

Table E1. Average annual *E. coli* loads and TMDL for the Cub Run watershed (cfu/yr)

WLA[1]	LA	MOS	TMDL
1.74×10^{10}	6.53×10^{13}	(implicit)	**6.53×10^{13}**

[1] The point source permitted to discharge in the Cub Run watershed are presented in section 5.2.

For Cub Run, the WLA represents less than 1% of the TMDL load. The required reduction of 99% is to be applied to each of the four non-point sources identified in the BST analysis.

The Cub Run TMDL development presented in this report is the first step toward the attainment of water quality standards. The second step is to develop a TMDL implementation plan, and the final step is the field implementation of the TMDL to attain water quality standards.

The Commonwealth intends for this TMDL to be implemented through a process of phased implementation of best management practices (BMPs). The development of the Cub Run TMDL requires a 99% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels (80%, 67%, 60%, and 50%) and their associated violation rates were assessed. Reduction curves similar to the maximum exceedance/reduction curve were plotted and are presented in this report.

Results also suggest that a majority of water quality violations are related to high flow events and could be due to runoff. Eighty-eight percent of samples collected at higher than median flow exceeded the water quality standard, while only 29% of samples collected at less than median flow exceeded the water quality standard. Among some of the BMPs effective in reducing bacteria coming from runoff include: riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be included in the eventual TMDL implementation plan for the watershed.

Public involvement in the development and implementation of TMDLs is essential. A public meeting was held in McGaheysville, Virginia on February 12, 2003 to discuss the process for TMDL development and the source assessment input. Approximately 34people attended. Copies of the presentation materials and the draft TMDL report were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and one set of written comments was received and responded to. These comments and the responses provided are being submitted to EPA under separate cover.

1. Introduction

Section 303(d) of the Clean Water Act and US Environmental Protection Agency's (EPA’s) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 1991).

The Commonwealth of Virginia's (Virginia’s) 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA) codifies the requirement for the development of TMDLs for impaired waters. Specifically section § 62.1-44.19:7 C states:

"The plan required by subsection A shall, upon identification by the Board of impaired waters, establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Board shall develop and implement pursuant to a schedule total maximum daily loads of pollutants that may enter the water for each impaired water body as required by the Clean Water Act. "

The EPA specifies that in order for a TMDL to be considered complete and approvable, it must cover the following eight elements:

1. It must be designed to meet applicable water quality standards,
2. It must include a total allowable load as well as individual waste load allocations and load allocations,
3. It must consider the impacts of background pollution,
4. It must consider critical environmental conditions or those conditions (stream flow, precipitation, temperature, etc.) which together can contribute to a worst-case exceedance of the water quality standard,
5. It must consider seasonal variations which together with the environmental variations can lead to a worst-case exceedance,
6. It must include an implicit or explicit margin of safety to account for uncertainties inherent in the TMDL development process,
7. It must allow adequate opportunity for public participation in the TMDL development process,
8. It must provide reasonable assurance that the TMDL can be met.

The following document details the development of a bacteria TMDL for Cub Run which was listed as impaired on Virginia’s 1998 303(d) Total Maximum Daily Load Priority List and Virginia’s 2000 and 2002 303(d) Report on Impaired Waters. The entire length of Cub Run, from its headwaters to confluence with the South Fork of the Shenandoah River, was listed as impaired due to a violation of Virginia's water quality standard for fecal coliform bacteria.

A glossary of terms used throughout this report is presented as Appendix A.

2. Physical Setting

2.1. Listed Water Bodies

Cub Run is located in Rockingham County in the Potomac and Shenandoah River Basin (USGS Hydrologic Unit Code 02070005). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Cub Run is VAV-B34R. The impaired segment includes the entire 13.94-mile length of Cub Run, from the headwaters to the confluence with the South Fork of the Shenandoah River. A map of the Cub Run watershed is presented in Figure 1.

Figure 1. Map of the Cub Run watershed

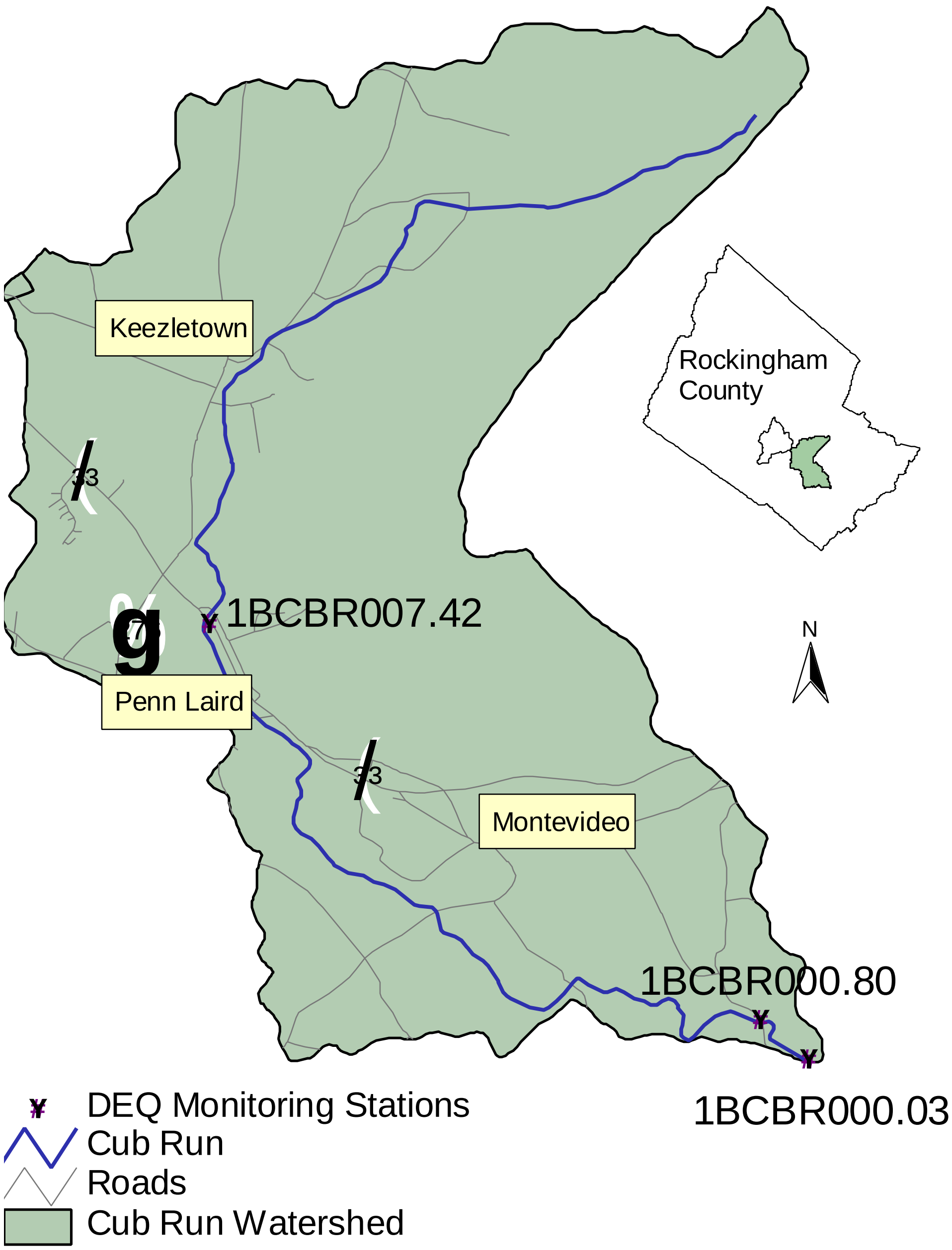


Table 1. Cub Run impaired segment description

Segment (segment ID)	Impairment	Upstream Limit Description	Downstream Limit Description	Miles Affected
Cub Run (VAV-B34R)	Fecal Coliform	Headwaters	Confluence with SF Shenandoah River	13.94

2.2. Watershed

2.2.1. General Description

The Cub Run watershed is located within Rockingham County, Virginia, and includes a very small portion within the city limits of Harrisonburg, Virginia. The Cub Run watershed is approximately 26.8 square miles and encompasses the towns of Keezletown, Penn Laird, and Montevideo. The headwaters of Cub Run begin on the southwestern slope of Massanutten Mountain. Cub Run flows southwest from its headwaters and turns south and then southeast to flow around the southern base of Massanutten Mountain. Cub Run continues flowing southeast until its confluence with the South Fork of the Shenandoah River. The Shenandoah River is tributary to the Potomac River, which flows into the Chesapeake Bay.

2.2.2. Geology, Climate, Land Use

Geology and Soils

Cub Run is entirely located within the Valley and Ridge physiographic province and the Valley of Virginia physiographic subregion. The Valley and Ridge province has developed on thick, folded beds of sedimentary rock that form a series of long, narrow parallel ridges and intervening valleys. The Valley of Virginia is underlain primarily by carbonate rocks and has a karst geology with many sinkholes, caves, and caverns.

Topography varies sharply in the watershed, with elevations ranging from 304 meters (1000 ft) above sea level at the mouth of Cub Run to 888 meters (2922 ft) above sea level at the peak of Massanutten Mountain (Figure 2). Major soil groups in the region are shown in Figure 3 using the State Soil Geographic (STATSGO) Data Base (STATSGO, 1994). In general, soils with high infiltration rates and low runoff potential are located in the valley while soils with low infiltration rates and high runoff potential tend to be found along the ridges. The valley soils also tend to be better suited for general development, septic systems, and agriculture than the ridges.

Figure 2. Elevation profile of the Cub Run watershed

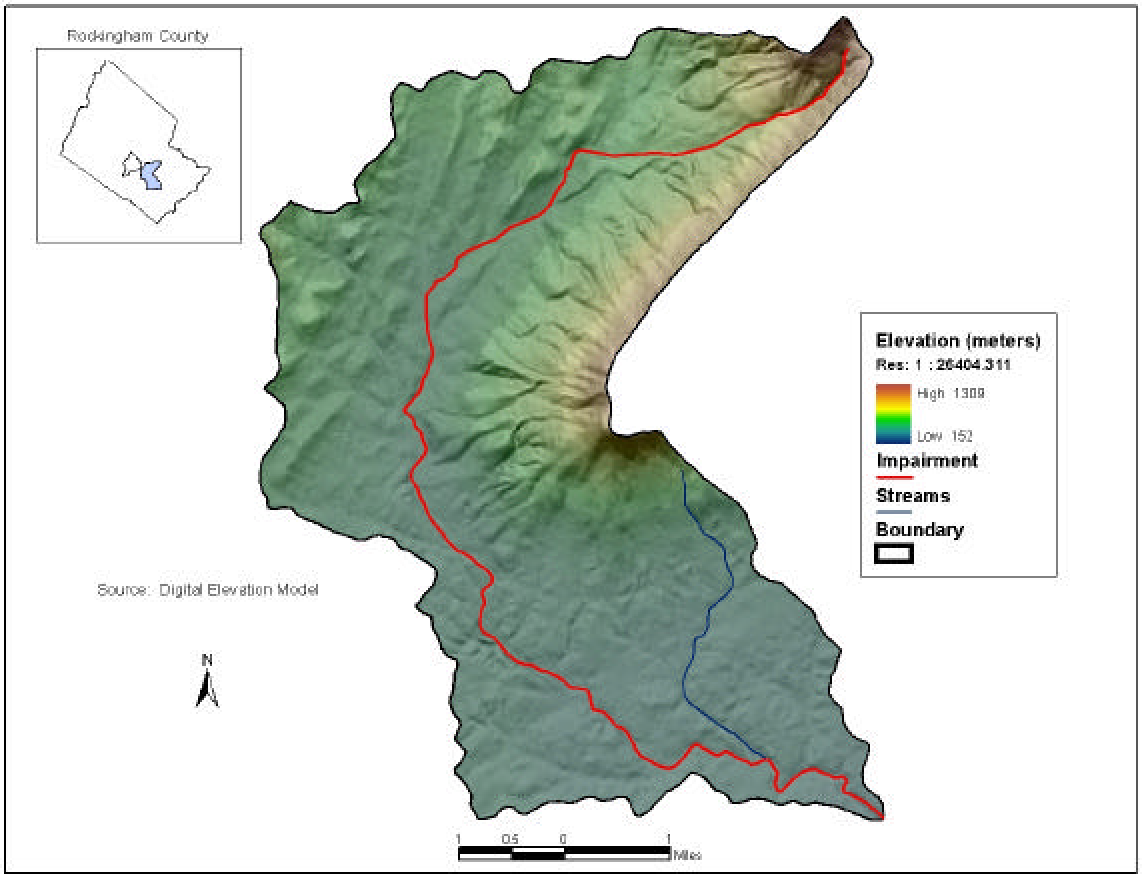
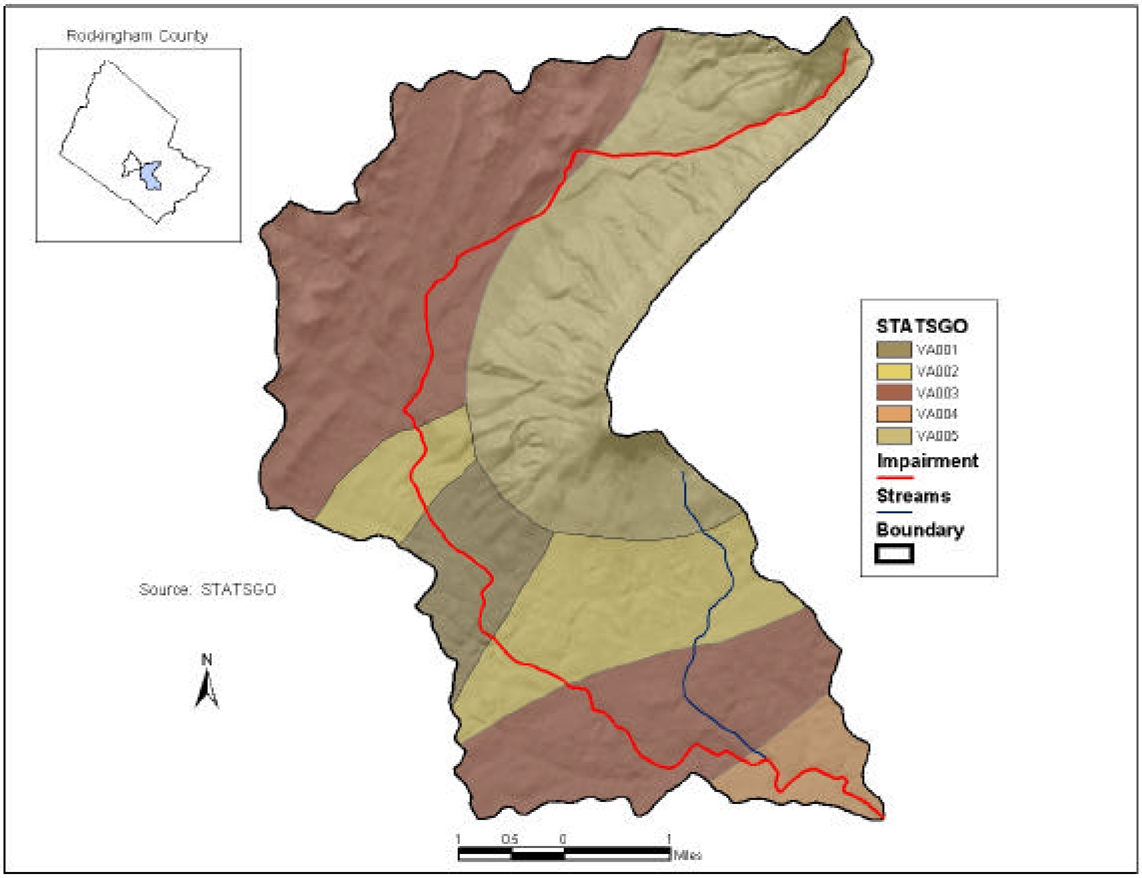


Figure 3. Major soil groups of the Cub Run watershed



Climate

The climate in the Cub Run watershed is typical of the temperate Mid Atlantic region. The average annual rainfall as recorded at Dale Enterprise, Virginia (~7 miles west of the study area) is 35.23 inches. Average temperatures vary from an average low of 22.3°F in January to an average high of 85.8°F in July. Table 2 presented below provides a summary of climate data for the Dale Enterprise, Virginia weather station (Hydrodata 2001).

Table 2. Climate summary for Dale Enterprise, Virginia (1948 - 2003)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	42.5	45.9	54.5	65.6	74.4	82.3	85.8	84.2	77.5	67.0	55.4	45.1	65.0
Average Min. Temperature (F)	22.3	24.5	31.0	39.8	49.0	57.3	61.6	60.0	53.3	42.2	33.5	25.4	41.7
Average Total Precipitation (in.)	2.20	2.15	2.93	2.68	3.58	3.30	3.81	3.82	3.39	2.59	2.51	2.28	35.23

Source: Southeast Regional Climate Center, 2003

Land Use

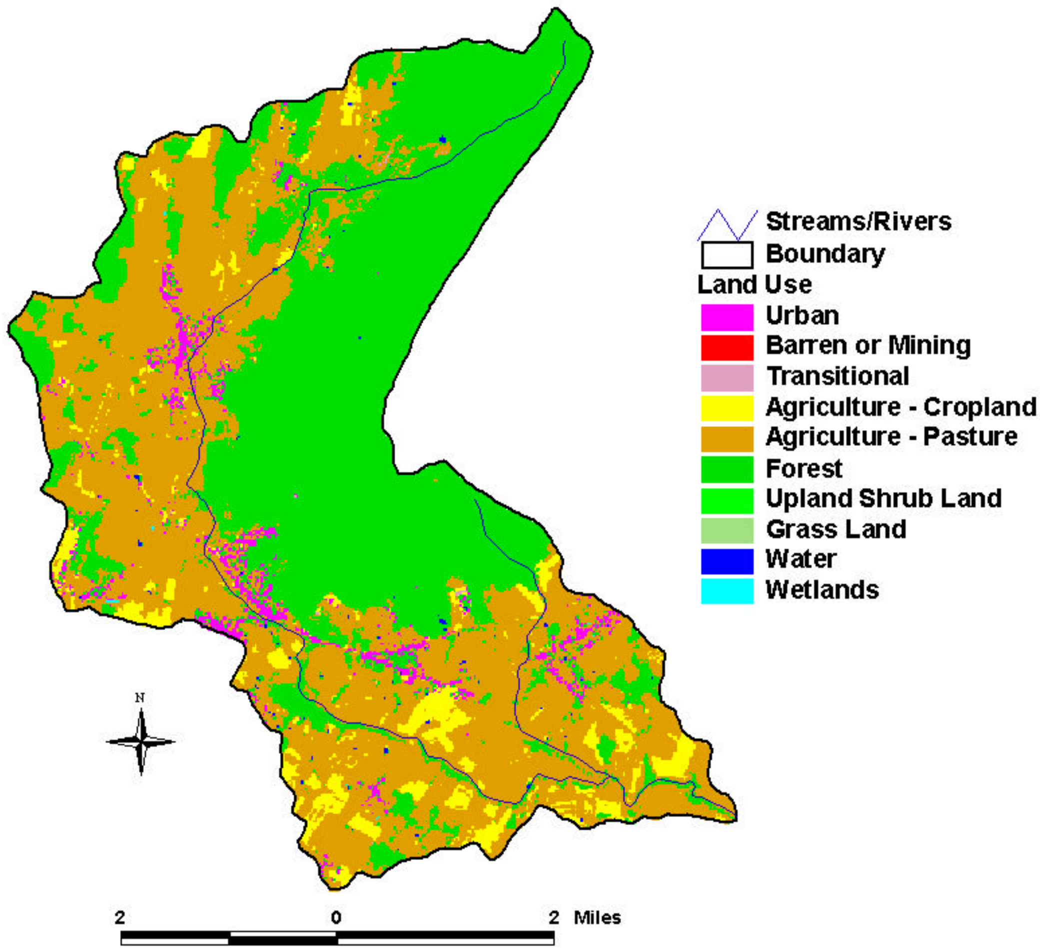
The Cub Run watershed study area is approximately 26.8 square miles or 17,127 acres. Pasture/hay land and forest dominate the land use in the watershed. Nearly half of the watershed (46.37%) consists of pasture and hay land, while deciduous, evergreen, and mixed forests comprise an almost equal portion of the watershed (45.33%). The remaining 8.3% of the watershed consists of row crops, residential areas, transitional areas, commercial areas, wetlands, grasses, and open water (Table 3).

The distribution of land use in the watershed is shown in Figure 4. The forested area of the watershed is mostly confined to the slopes of Massanutten Mountain, while the lower elevations are primarily used for agriculture. The land directly bordering Cub Run (riparian area) is predominantly pasture, with forest in the headwaters and narrow forest buffers along some downstream portions of the stream. Urban and residential areas in the watershed are primarily located near Keezletown and along the Rt 33 corridor, both of which are in close proximity to portions of the stream.

Table 3. Land use in Cub Run watershed

Land Use	Area (acres)	Area (%)
Open Water	32.2473	0.19
Low Intensity Residential	416.546	2.43
Transitional	7.78382	0.05
Deciduous Forest	6492.15	37.91
Evergreen Forest	166.796	0.97
Mixed Forest	1104.19	6.45
High Intensity Commercial/Industrial/Transportation	5.78227	0.03
Pasture/Hay	7942.39	46.37
Row Crops	913.153	5.33
Other Grasses (Urban/recreational; e.g. parks, lawns)	42.0326	0.25
Emergent Herbaceous Wetlands	3.78071	0.02
Total:	17126.8	100.00

Figure 4. Land use in the Cub Run watershed



3. Description of Water Quality Problem/Impairment

Cub Run was listed as impaired on Virginia's 1998 303(d) Total Maximum Daily Load Priority List and Report and the 2002 303(d) Report on Impaired Waters (VADEQ, 1998 & 2002) due to violations of the State's water quality standard for fecal coliform bacteria. Out of 18 samples collected during the 1998 assessment period, 5 (or 28%) violated the fecal coliform water quality standard of 1000 cfu/100ml. In the 2000 assessment period, 4 out of 19 samples (21%) violated the water quality standard. During the most recent 2002 assessment period, 5 of 23 samples (or 22%) violated the standard.

Table 4 presents a summary of all of the fecal coliform data collected by DEQ on Cub Run. Fecal coliform data have been collected from three separate monitoring locations (1BCBR000.03, 1BCBR000.80, and 1BCBR007.42), which are depicted in Figure 1. The impairment listing in the 1998, 2000, and 2002 assessments were based on sampling at the 1BCBR000.80 monitoring station. A total of 41 samples were collected from this site from 1992 through 2001, and 24% of those samples exceeded the water quality standard. Since the 2002 assessment, additional monitoring stations upstream

(1BCBR007.42) and downstream (1BCBR000.03) of the listing station have been added on Cub Run. Results from each of these stations are consistent with those from the initial listing station. Exceedances of the 1000 cfu/100ml fecal coliform standard were observed at each of the monitoring stations, with exceedance rates of 45% at the most upstream station and 27% at the most downstream station. The higher violation rate at the upstream station is likely due to lower flow and limited dilution at this upstream station.

Table 4. Fecal coliform data collected by DEQ on Cub Run

Station	Date of First Sample	Date of Last Sample	Number of Samples	Average (cfu/100ml)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Number of Exceed-ances*
1BCBR000.03	07/24/2002	09/15/2003	15	2429	10	22000	4
1BCBR000.80	01/07/1992	06/20/2001	41	1005	100	8000	10
1BCBR007.42	08/08/2001	06/26/03	11	968	25	3100	5
1998 305(b) Data (July 1, 1992 to June 30, 1997)							
1BCBR000.80	07/27/1992	06/12/1997	18	1361	100	8000	5
2000 305(b) Data (January 1, 1994 to December 31, 1998)							
1BCBR000.80	01/05/1994	11/30/1998	19	1147	100	8000	4
2002 305(b) Data (January 1, 1996 to December 31, 2000)							
1BCBR000.80	04/25/1996	11/29/2000	23	626	100	2000	5

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100ml

A time series of data collected from each of the Cub Run monitoring stations is presented in Figure 5. The horizontal line at the 1000 cfu/100ml mark represents the instantaneous fecal coliform water quality standard that was applicable at the time of the 1998, 2000, and 2002 assessments. The data points above the 1000 cfu/100ml line illustrate violations of the then-applicable water quality standard. Throughout the period of record for each of the monitoring stations, violations of the 1000 cfu/100ml standard were observed (Figure 5). In January 2003, the fecal coliform instantaneous standard was lowered from 1000 to 400 cfu/100ml (see Section 4.2). The dashed line in Figure 5 indicates this new standard. Using the new standard, overall violation rates (including all sites and all times) increase from 28% to 52%.

In addition to fecal coliform results, *E. coli* was enumerated in samples from Cub Run collected after July 2002. A time series of *E. coli* results from Cub Run are shown in Figure 6. The dashed line in this figure represents the instantaneous *E. coli* standard of 235 cfu/100ml that was adopted in January 2003. Approximately 60% of samples overall (including all sites and all times) exceeded this *E. coli* standard.

Figure 5. Time series of fecal coliform concentrations in Cub Run

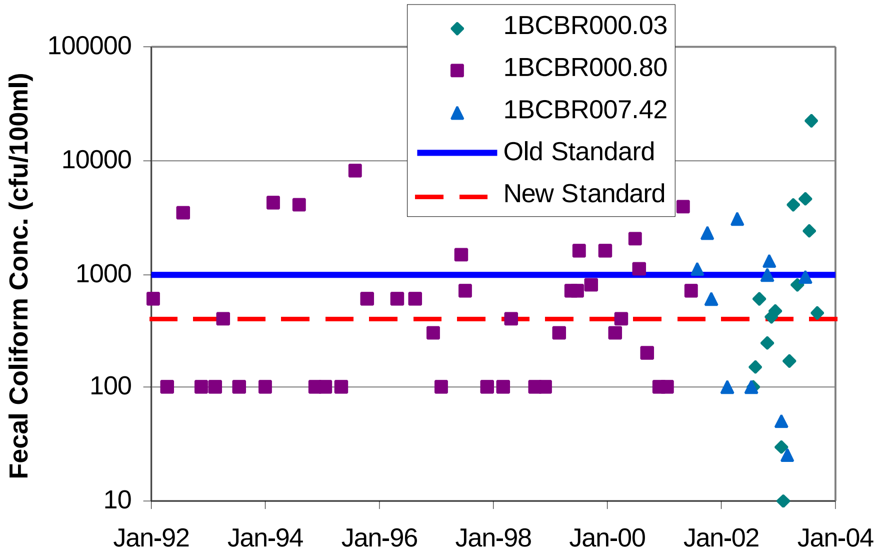
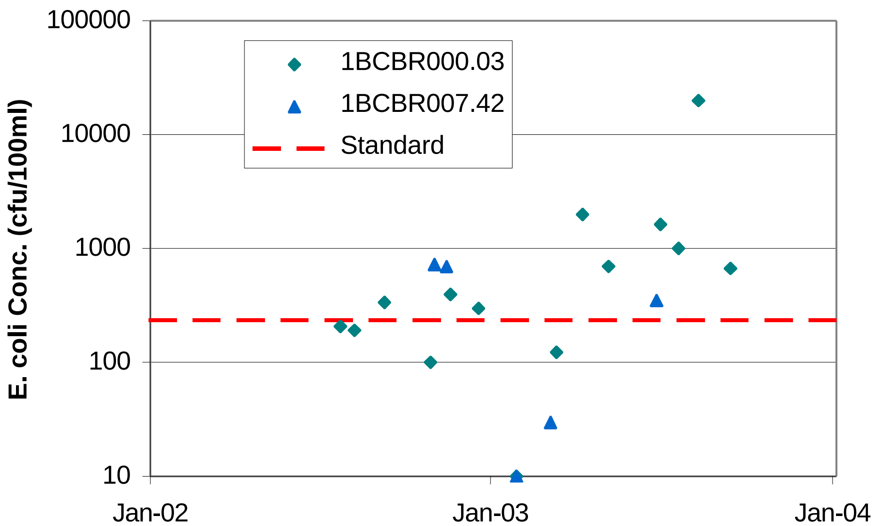


Figure 6. Time series of *E. coli* concentrations in Cub Run



4. Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term *"water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."*

As stated above, Virginia water quality standards consist of a designated use or uses and a water quality criteria. These two parts of the applicable water quality standard are presented in the sections that follow.

4.1. Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10A), *"all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."*

As stated above, Cub Run must support all designated uses and meet all applicable criteria.

4.2. Applicable Water Quality Criteria

The applicable water quality criteria for bacteria in Cub Run have changed since the initial listing on the 303(d) report. Following EPA recommendations, the Virginia Department of Environmental Quality (DEQ) proposed more stringent fecal coliform bacteria standards as well as new standards for *Escherichia coli* (*E. coli*) bacteria. These new standards were adopted by the State Water Control Board in May 2002, public noticed in June 2002, approved by the USEPA in November 2002, and were effective January 15, 2003.

The EPA recommendation that states adopt *E. coli* and enterococci (saltwater) standards stems from a stronger correlation between the concentration of *E. coli* and enterococci organisms and the incidence of gastrointestinal illness. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. *E. coli* is a subset of the fecal coliform group; thus a waterbody listed as implied for fecal coliform is considered to be listed for *E. coli* as well.

Although Cub Run was listed as impaired due to a violation of the previous fecal coliform standard, the TMDL must be developed to meet the new *E. coli* bacteria standard. The interim fecal coliform bacteria standard presented below will not apply to this TMDL since 15 *E. coli* bacteria samples were collected as part of this study.

New Bacteria Standards

For a non-shellfish supporting water body such as Cub Run to be in compliance with Virginia bacteria standards for primary contact recreational use, the DEQ specifies the following criteria (9 VAC 25-260-170):

1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.

2. E.coli and enterococci bacteria per 100ml of water shall not exceed the following:

Table 5. Applicable water quality standards

Parameter	**Geometric Mean[1] (cfu/100ml)**	**Single Sample (cfu/100ml)**
E.coli (fresh water)	126	235
Enterococci (saltwater & Transition Zone 3)	35	104

[1] for two or more samples taken during a calendar month.

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per calendar month, the instantaneous criterion is applied; for a higher sampling frequency, the geometric mean criterion is applied.

For Cub Run, the TMDL is required to meet the instantaneous criterion since the load-duration approach used to develop the TMDL for Cub Run yields the maximum allowable bacteria concentration under any given flow condition. Unlike a continuous time series simulation, the flow duration approach does not yield daily bacteria concentrations, which are needed to apply the geometric mean standard. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect bacteria loading.

5. Assessment of Bacteria Sources

The assessment of bacteria sources in traditional bacteria TMDL studies involves estimating loads from sources in the watershed and developing a computer model to establish the links between estimated loads and actual in-stream bacteria concentrations.

In a load-duration bacteria TMDL, source assessment is accomplished by determining the relative contribution by source of the fecal bacteria contained in a sample of stream water. This method of source identification is achieved through microbial source tracking (MST). MST methods that specifically use bacteria as the target organism are referred to collectively as bacteria source tracking (BST) methods. MST has been applied to study microbial ecology of environmental systems for years and are now being applied to help improve water quality by identifying problem sources and determining the effect of implemented remedial solutions. Management and remediation of water pollution would be more cost effective if the correct sources could be identified (Simpson, 2002).

To support BST analyses in load-duration TMDLs, bacteria loading in a watershed is also estimated. These load estimates are broken into point and non-point sources. It is important to note that the non-point source load estimates represent loading to the surface of the watershed; they are not estimates of in-stream loads.

The following sections present BST analysis and point- and non-point source load estimates.

5.1. Bacteria Source Tracking (BST)

Background

MST methods can be divided into three categories: molecular (genotype), biochemical (phenotype), and chemical. Molecular methods may offer the most precise identification of specific types of sources but are limited by high per-isolate costs and detailed and time-consuming procedures. They are not yet suitable for assaying large numbers of samples in a reasonable time frame. Biochemical methods (BST) may or may not be as precise, but are more simple, quicker, less costly, and allow large numbers of samples to be assayed in a short period of time (Hagedorn, 2002).

Several biochemical BST methods are in various stages of development. Among these are Antibiotic Resistance Analysis (ARA), F-Specific (F+ or FRNA) Coliphage, Sterols or Fatty Acid Analysis, Nutritional Patterns, and Fecal Bacteria Ratios. Of these, ARA has been chosen as the BST method for this TMDL study.

The ARA method uses fecal streptococcus (including the enterococci) and/or *E. coli* and patterns of antibiotic resistance for separation of sources. The premise is that human fecal bacteria will have the greatest resistance to antibiotics and that domestic and wildlife animal fecal bacteria will have significantly less resistance (but still different) to the battery of antibiotics and concentrations used. Most investigators are testing each isolate on 30 to 70+ antibiotic concentrations (Hagedorn, 2002). A more detailed description of the ARA method used by MapTech, Inc. in support of this TMDL is presented in Appendix B.

BST Sampling and Results

DEQ staff collected a total of 15 ambient water quality samples from the most downstream monitoring station on Cub Run (1BCBR000.03). Thirteen of these samples were cooled and shipped on ice to MapTech, Inc. (MapTech) for BST analysis. The BST analyses performed by MapTech determined the relative contribution of overall bacteria by human, pet, livestock, and wildlife sources. Fecal and *E.coli* bacteria were also enumerated as part of the analyses performed by MapTech. Results of the Cub Run BST sampling program are presented in Table 6.

Table 6. Cub Run (station 1BCBR000.03) bacteria source tracking results

Sample Date	Fecal Coliform (cfu/100ml)	*E. coli*[1] (cfu/100ml)	BST Distribution[2]			
			Wildlife	Human	Livestock	Pets
09/09/2002	600	*330*	21%	17%	62%	0%
10/28/2002	250	100	33%	0%	46%	21%
11/19/2002	410	*400*	8%	4%	38%	50%
12/17/2002	470	*300*	8%	0%	92%	0%
01/28/2003	30	10	61%[3]	13%[3]	13%[3]	13%[3]
02/11/2003	10	<1	--	--	--	--
03/11/2003	170	120	0%	50%	4%	46%
04/08/2003	4100	*2000*	8%	4%	75%	13%
05/06/2003	800	*700*	38%	4%	33%	25%
06/30/2003	4500	*1600*	46%	8%	0%	46%
07/21/2003	2400	*1000*	42%	4%	50%	4%
08/11/2003	22000	*20000*	58%	0%	25%	17%
09/15/2003	450	*680*	59%	12%	17%	12%
		Average	32%	10%	38%	21%
		Standard Deviation	22%	14%	28%	18%

[1] Values in red italics exceed the current water quality standard for bacteria.
[2] Shaded values are statistically significantly different from zero. Unshaded values are not significantly different from zero based on a z-test with alpha=0.10.
[3] The bacterial concentration in this sample was too low to obtain a sufficient number of isolates for source tracking, such that percentages presented are not significantly different from zero based on a z-test with alpha=0.10.

BST analysis determined that all source categories (wildlife, human, livestock, and pets) contributed a significant portion of the bacterial load in one or more samples. The contribution from human sources was the smallest, with an average of only 10% and with only three samples representing significant contribution from human sources. Seven of the thirteen samples contained significant contributions from wildlife, and eight of the thirteen samples contained significant contributions from pets. The average contribution from wildlife was 32%, and the average contribution from pets was 21%. BST results indicated that livestock was the largest contributor to the bacterial load in Cub Run. Nine of the thirteen samples represented significant contributions from livestock. The livestock contribution averaged 38% across all samples.

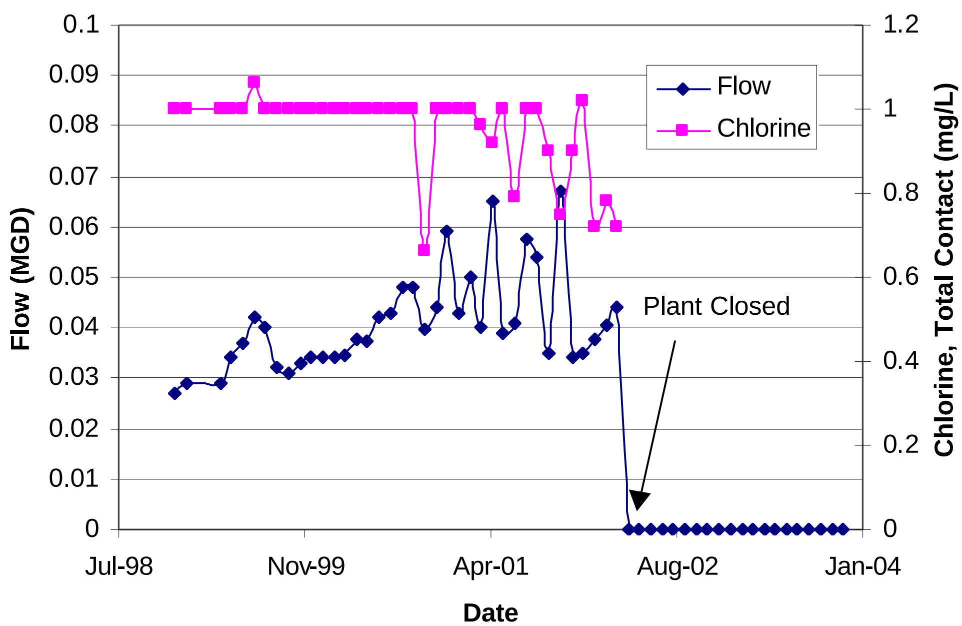
In addition to evaluating overall average contributions of bacteria from the various sources, it is important to consider the relative contributions in those samples where the bacteria standard was violated. For instance, the distribution of sources contributing to an *E. coli* concentration of 10 cfu/100ml is less important than the distribution of sources contributing to an *E. coli* concentration of 1000 cfu/100ml when it comes to implementing strategies to reduce violations of the bacteria water quality standard. When average contributions are calculated from just those samples that exceeded the bacteria standard, the distribution is 32% wildlife, 6% human, 44% livestock, and 19% pets. When considering only those samples that exceeded the bacteria standard, the contribution from livestock is slightly higher, and the contribution from humans is slightly lower.

5.2. Point Sources

Bacteria loading from point sources such as sewage treatment plants, small commercial establishments, schools, homes, and businesses require permits under the Virginia Pollution Discharge Elimination System (VPDES) permit program. Within the Cub Run watershed, there was one individual VPDES permit and ten general domestic sewage permits that would have the potential to discharge bacteria. The one individual VPDES permit (permit number VA0088501) was for the Lawyers Road Sanitary District Sewage Treatment Plant (STP), which is no longer in operation. This sewage treatment plant was permitted at a design flow of 0.08 MGD and treated domestic sewage. In 2002, the plant was closed and a pump station was installed to divert the waste flow to the McGaheysville sewage treatment plant. This project was completed in February 2002, and there has been no discharge at the site since that time. Because the Lawyers Road Sanitary District STP no longer exists and no longer has a potential to discharge, a waste load allocation will not be assigned to this permit as part of the TMDL. The facility did, however, discharge treated domestic sewage during the time of bacterial monitoring on Cub Run and may have contributed to the overall bacterial loading at that time. For this reason, the former discharge history of this facility is described below.

The Lawyers Road STP is permitted to discharge an average of 80,000 gallons per day (gpd) or 0.08 million gallons per day (MGD). From 1999 through the time the facility was closed in 2002, the average flow ranged from 0.027 to 0.067 MGD. Figure 7 shows the variation of the Lawyers Road STP flow from January 1999 to January 2004. After the facility was closed in the spring of 2002, no flow has been discharged.

Figure 7. Lawyers Road STP average daily flow and chlorination level



Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100ml. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform concentrations, are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the 200 cfu/100ml limit.

During operation, the Lawyers Road STP used chlorine to disinfect the wastewater. Reported residual chlorine concentrations are presented in Figure 7. Chlorine concentration data from January 1999 until March 2002 indicate that total residual chlorine (TRC) concentrations ranged from 0.66 to 1.06 mg/L. This indicates that adequate disinfection was achieved at the plant.

In addition to the Lawyers Road STP, there are currently 10 small permitted domestic sewage discharges in the Cub Run watershed. These discharges are typically single-family alternative treatment systems that can be installed when septic systems are not an option due to location or soil characteristics. The general permits issued for these discharges allow no more than 1000 gal/day from the discharge and require *E. coli* levels below the water quality standard of 126 cfu/100ml. The 10 general permitted point sources are presented in Table 7.

Wasteload allocations for the permitted point sources were calculated by multiplying the permitted discharge concentration of *E. coli* (126 cfu/100ml as a geometric mean) times the design flow (1000 gal/day) times the appropriate unit conversions. The calculation is presented in Appendix C. The total wasteload from permitted point sources was calculated as 1.74×10^{10} cfu/yr. To allow for expansion of current facilities (in the case of individual permits) or expansion in the number of general permits within the watershed, multiples of two times and five times the existing wasteload were calculated. The point source wasteload allocation set for the Cub Run TMDL was 8.70×10^{10}, which allows for expansion of five times the existing permitted wasteload (Appendix E). This expansion will not degrade water quality or cause instream violations of the bacteria water quality standard, because each permitted point source is required to discharge bacteria at a concentration below the water quality standard.

Table 7. VPDES point source facilities and loads

Permit Number	Facility Name	Receiving Stream	Watershed ID	Design Flow (MGD)	*E. coli* Effluent Limit (cfu/100ml)	*E. coli* Wasteload Allocation (cfu/yr)
VAG401012	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG408050	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG401611	C&D Pools and Spas	Cub Run	VAV-B34R	0.001	126	1.74×10^9
VAG401528	Massanutten Exxon	Cub Run	VAV-B34R	0.001	126	1.74×10^9
VAG401800	Truth Light & Life Mission	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG401835	Loker Auto Sales	Cub Run	VAV-B34R	0.001	126	1.74×10^9
VAG401471	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG401493	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG401439	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
VAG401914	Private Residence	Cub Run UT	VAV-B34R	0.001	126	1.74×10^9
Existing WLA					Total	1.74×10^{10}
	Expansion Matrix				Total x 2	3.48×10^{10}
					Total x 5	8.70×10^{10}

5.3. Non-Point Sources

In order to gain an understanding of non-point source loading in the Cub Run watershed, bacteria loads for typical non-point sources were estimated. These estimates were based upon animal and human population data sets, typical waste production rates and typical bacteria densities in waste products.

Currently published values for fecal bacteria production rates are primarily in terms of fecal coliform. There is little data on *E. coli* production; however, studies have shown that though minor variability will exist between sources, *E. coli* represents roughly 90-95% of fecal coliforms contained in "as-excreted" fecal material (Yagow, 2003). This implies that the relative bacteria contribution by source should remain constant.

It is important to note that the bacteria loads presented in the following sections on non-point sources represent "as-produced" loads. This is to say that some portion of an estimated load may not be available to be transported to Cub Run in runoff.

5.3.1. Humans and Pets

Bacteria loading from human sources can come from straight pipes, failing septic systems, and land-applied biosolids. Failing septic systems are typically manifested by effluent discharging to the ground surface where the bacteria-laden effluent is then available to be washed into a stream as runoff during a precipitation event. In contrast, discharges from straight pipes are typically directly deposited to streams.

All biosolids can contain a certain concentration of fecal bacteria. When biosolids are applied to the land surface, the potential exists for a portion of these fecal bacteria to be transported to a stream as runoff during storm events.

Straight Pipes

The Central Shenandoah District office of the Virginia Department of Health reported no known straight pipes in the Cub Run watershed.

Septic Systems

Based on 2000 U.S. Census data, the Cub Run watershed is populated by approximately 2495 residents living in approximately 1174 households. Rockingham County provides sewerage for a portion of the Cub Run watershed. Of the 1174 households, 198 were estimated to be sewered based on a census classification of urban for these households. Approximately 976 households were classified as rural and were estimated to be served by septic systems. Using an average of 2.12 people per household (2495 residents / 1174 households), a wastewater production rate of 75 gallons per day per person (Geldreich, 1978), and a fecal coliform density of 1.04×10^6 cfu/100ml (MapTech, 2002), the total septic load in the Cub Run watershed is estimated to be 2.23×10^{15} cfu/yr. Of this total septic load, only the load from failing septic systems would be available as runoff.

Septic system failure rates depend largely on the age of the septic system. Surveys of failing septic systems in other Virginia watersheds have yielded a formula for calculating a rate of septic system failures for a given area. Based on information gathered for other TMDLs (BSE, 2003a), it was estimated that 40% of homes built prior to 1967 had failing septic systems, 20% of homes built between 1967 and 1987 had failing septic systems, and 3% of homes built after 1987 had failing septic systems. Using these estimates and the age of homes from 2000 census data, it was estimated that 209 homes in the Cub Run watershed have failing septic systems. The estimated bacterial load from these 209 failing septic systems that would be available for runoff is 4.77×10^{14} (Table 8).

Biosolids

In the Commonwealth of Virginia, the VDH and the DEQ regulate biosolids generation and application to the land surface. The DEQ regulates the generation of biosolids and the land application of those biosolids by the generator. The VDH regulates contractors who transport and spread biosolids; the biosolids can be from in-state or out-of-state sources. The DEQ comprehensive environmental database was queried, and no dischargers in the Cub Run hold permits allowing the land application of biosolids.

Pets

The number of pets in the watershed was estimated based on the number of households. Assuming an average of 1.7 dogs and 2.1 cats per household (National Pet Owner Survey, American Pet Products Manufacturers Association, 2001-2002), the estimated pet population in the Cub Run watershed consists of 1995 dogs and 2465 cats. Using the waste production rates and fecal coliform densities from MapTech (2002), the total bacteria loads from dogs and cats in the Cub Run watershed are 1.57 x 10^{14} and 1.57 x 10^{8} cfu per year, respectively. Table 8 presents the calculation of human and pet loads in the watershed. It should be noted that the numbers presented in Table 8 represent loads available for runoff and not in-stream loads.

Table 8. Estimated fecal coliform production from humans and pets in the Cub Run watershed

Source	Population	Waste Production Rate	Waste Fecal Coliform Density	Total Est. Annual Fecal Production
Failing Septic Systems	209 systems x 2.12 people/system = 443 people	75 gal/day/person x 37.85412 100ml/gal x 365 days/yr = 1.04 x 10^{6} 100ml/yr/person *	1.04 x 10^{6} cfu/100ml *	4.77 x 10^{14} cfu/yr
Dogs	1995 dogs	450 g/dog/d **	4.8 x 10^{5} cfu/g **	1.57 x 10^{14} cfu/yr
Cats	2465 cats	19.4 g/cat/d **	9 cfu/g **	1.57 x 10^{8} cfu/yr

* Geldreich, 1978. A conversion factor of 37.85412 was used to convert gallons to 100ml.

** MapTech, 2002.

5.3.2. Livestock

Fecal matter from livestock can be deposited directly to the stream in instances where livestock have stream access, or the fecal matter can be transported to the stream in surface runoff from grazing or pasture lands.

Estimates of livestock numbers in the Cub Run watershed were obtained from the Department of Conservation and Recreation’s GIS database of confined animal feeding operations (CAFOs) and from the 1997 Census of Agriculture (USDA, 1999). Estimates for dairy cows and poultry (chicken and turkey) were obtained from the DCR database. For beef cattle and sheep, which are not necessarily associated with CAFOs, numbers were estimated from the Rockingham County livestock numbers presented in the 1997 Census of Agriculture. Estimates Cub Run were obtained by multiplying Rockingham County estimates by 5.3%, the percentage of Rockingham County hay and pasture land within the Cub Run watershed. Table 9 presents the livestock population estimates, fecal production rates, and estimated annual fecal loads in the watershed. It should be noted that the numbers presented in Table 9 represent loads generated within the watershed and not in-stream loads.

Table 9. Estimated annual fecal coliform production from livestock in the Cub Run watershed

Source	Population		Waste Production Rate[a] (lbs/animal/day)	Fecal Density[a] (cfu/g)	Total Fecal Production[b] (cfu/yr)
	Rockingham County	Cub Run Watershed			
Beef cattle	25,566	1,357	46.4	1.01×10^{5}	1.05×10^{15}
Milk cows	25,477	990	120.4	2.58×10^{5}	5.09×10^{15}
Sheep	7,557	401	2.4	4.30×10^{4}	6.85×10^{12}
Turkey	1,929,828	209,700	0.25	7.28×10^{5}	6.32×10^{15}
Chicken	117,987,208	231,000	0.04	3.64×10^{6}	5.57×10^{15}

[a] Values obtained from MapTech, 2002 (for beef cows, milk cows, and sheep) and BSE, 2003b (for turkey and chicken).

[b] A conversion factor of 453.6 was used to convert pounds to grams.

5.3.3. Wildlife

Like livestock, fecal matter from wildlife can be either deposited directly to the stream, or it can be transported to the stream in surface runoff from woods, pastureland and cropland. Direct deposition to streams varies with species, e.g. beaver spend most of their time in water; therefore most of their fecal matter would be directly deposited to the stream.

Wildlife populations in the Cub Run watershed were estimated based on wildlife densities used in developing the Linville Creek TMDL (BSE, 2003b). Habitat was assigned as follows:

- deer: all land use categories
- raccoon: 600 ft buffer around streams and impoundments
- muskrat: 66 ft buffer around streams and impoundments in forest and cropland
- beaver: 300 ft buffer around streams and impoundments in forest and pasture
- goose: 300 ft buffer around main streams
- duck: 300 ft buffer around main streams
- wild turkey: entire watershed except urban and farmstead

Based on these habitat descriptions, the landuse and stream miles in the watershed were used to estimate the total acres of habitat available for each wildlife species. Total habitat is displayed in Table 10. The habitat area was then multiplied by the population densities for each species (BSE, 2003b) to obtain an estimate of the number of animals in the watershed. The number of animals was then multiplied by the range of literature values for waste production rates to obtain the total fecal coliform production from each wildlife species in the watershed (Table 10). Summing the fecal coliform load from all wildlife sources, an estimated 9.88×10^{13} to 4.95×10^{14} cfu/yr are deposited in the watershed. It should be noted that only a portion of this load would likely reach the stream and contribute to in-stream loads.

Table 10. Estimated fecal coliform production from wildlife in the Cub Run watershed

Source	Habitat (acres)	Population Density (an/acre)[a]	Watershed Population (an)	Waste Production Rate (cfu/an/day)[b]		Total Fecal Coliform Production (cfu/yr)	
				Low	*High*	*Low*	*High*
Deer	17,127	0.047	805	1.52×10^{8}	3.60×10^{8}	4.47×10^{13}	1.06×10^{14}
Wild Turkey	7,842	0.01	78	4.26×10^{5}	9.3×10^{7}	1.21×10^{10}	2.65×10^{12}
Muskrat	47	2.75	129	2.5×10^{7}	1.90×10^{8}	1.18×10^{12}	8.95×10^{12}
Beaver	633	0.015	9	2.0×10^{5}	3.0×10^{6}	6.57×10^{8}	9.86×10^{9}
Raccoon	1265	0.07	89	2.05×10^{7}	5.0×10^{9}	6.66×10^{11}	1.62×10^{14}
Goose	633	0.1092	69	5.87×10^{4}	2.25×10^{9}	1.48×10^{9}	5.67×10^{13}
Duck	633	0.0936	59	2.43×10^{9}	7.35×10^{9}	5.23×10^{13}	1.58×10^{14}
Total						9.88×10^{13}	4.95×10^{14}

[a] BSE, 2003b
[b] Ranges obtained from MapTech, 2002; Tetra Tech, 2002; and Virginia DEQ, 2004.

6. TMDL Development

One of the major obstacles to improving stream water quality is that the potential sources of bacteria are numerous and the dominant sources and/or pathways are generally unknown. This can make it difficult to direct effective cleanup efforts.

Typical pathogen TMDLs are completed by developing watershed-based computer simulations that establish links between sources and in-stream water quality. While effective, the effort required to develop modeled TMDLs can be costly. In an effort to complete pathogen TMDLs in a timely and cost-effective manner, the use of load-duration analyses has been investigated. It has been determined that the load-duration method of calculating a TMDL produces a result only slightly more conservative than if the TMDL had been determined through computer modeling.

The load duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. Exceedances that occur under low flow conditions are generally attributed to loads delivered directly to the stream such as straight pipes and livestock with access to the stream. Exceedances that occur under high flow conditions are typically attributed to loads that are delivered to the stream in stormwater runoff. Exceedances occurring during normal flows can be attributed to a combination of runoff and direct deposits.

The following sections detail the development of the load-duration TMDL and associated allocations.

6.1. Load-Duration Curve

Development of a load-duration curve begins with establishing a daily flow record for the stream. For streams that do not have permanent flow gauging stations, daily flows must be obtained by using a reference stream approach. A nearby reference gauging station is selected based on the correlation of flows at that site with several measurements in the target stream. A regression equation is then developed based on the reference and target stream flows. Daily flows in the target stream can then be predicted from reference stream flows using the regression equation.

Once daily flow records are generated for the target stream, a flow-duration curve can be developed. The flow-duration curve is a cumulative frequency distribution of daily flow values. The curve extends from very high flows that are exceeded very infrequently (e.g., a frequency near 0%) to very low flows that are almost always exceeded (e.g., a frequency near 100%). By multiplying flow values by the concentration of a pollutant, flow-duration curves can be transformed to load-duration curves for that pollutant. Similarly to the flow-duration curve, the load-duration curve is a cumulative frequency distribution of pollutant loads.

Load-duration curves are useful for TMDL development because they depict the load of a pollutant delivered across a range of flow regimes. Actual pollutant loads, based on the product of measured pollutant concentrations and flow, can be plotted along the load-duration curve to determine the flow regimes under which water quality violations typically occur. The total maximum daily load (TMDL) can also be determined from the load-duration curve by plotting the product of maximum water quality standard concentrations and flow.

The following sections detail the flow data for Cub Run, the development of a flow-duration curve for Cub Run, and the creation of a load-duration curve for Cub Run.

6.1.1. Flow Data

In the Cub Run watershed, there are no permanent flow gauging stations, so the reference stream approach was used to generate daily flow values for Cub Run. A temporary flow monitoring station was established on Cub Run at the most downstream water quality monitoring station (1BCBR000.03). This station was given a USGS stream gauging number of 01628630. Ten individual flow measurements were made at this station over a range of flow conditions (from 0.11 to 39.2 cfs). These flow measurements were compared to flows at three nearby permanent gauging stations. These reference flow stations are shown in Figure 8 and described in Table 11.

Figure 8. Location of reference flow gauging stations in relation to Cub Run

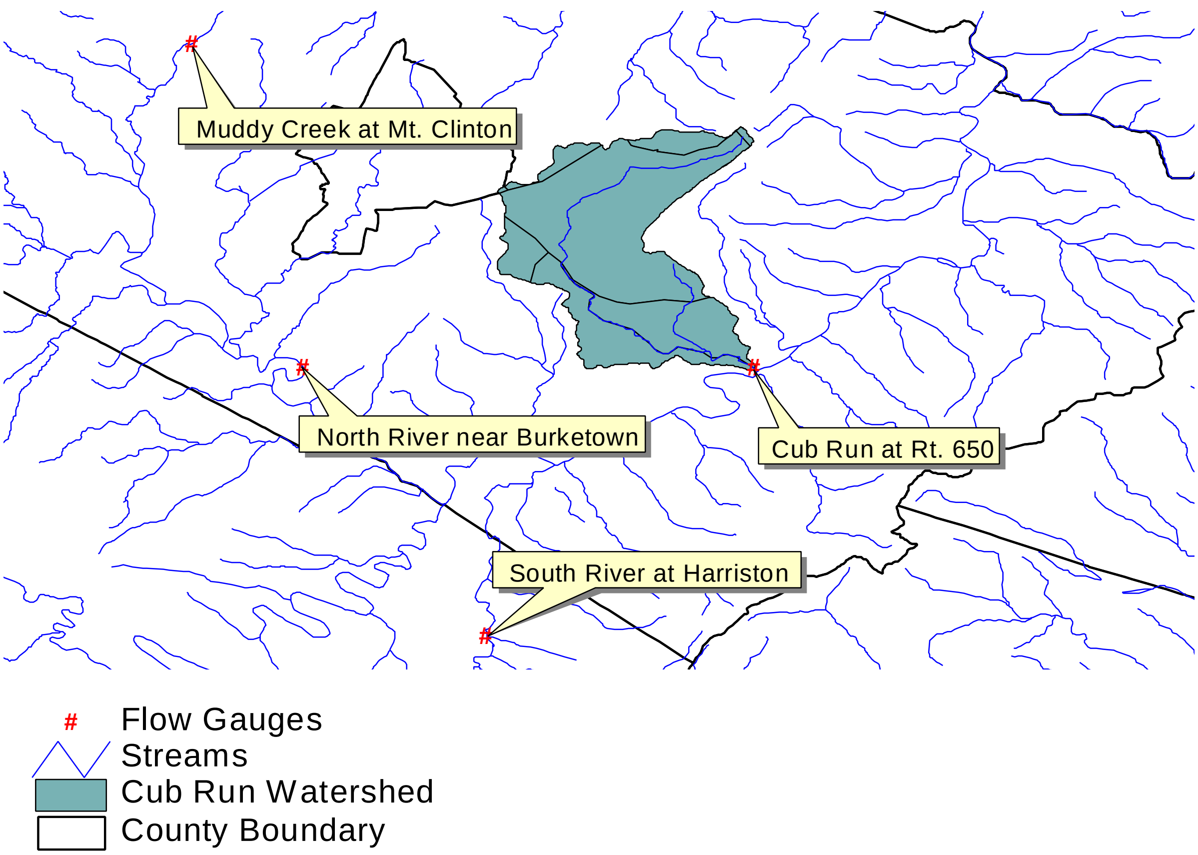


Table 11. Comparison of reference flow gauging stations to Cub Run

	Name	USGS #	HUC	Drainage Area (mi^2)	Distance from Target (mi)	Correlation with Target (r^2)
Target	Cub Run at Rt. 650	01628630	2070005	26.8	-	-
Reference	North River near Burketown	01622000	2070005	379	10.36	0.9685
	Muddy Creek at Mt. Clinton	01621050	2070005	14.2	16.4	0.8981
	South River at Harriston	01627500	2070005	212	10.4	0.9495

Correlations between Cub Run and the three reference flow gauging stations were very high, with r-squared values ranging from 0.8981 to 0.9685. The highest correlation was with the North River station near Burketown. This station was selected as the reference flow station for determining Cub Run flows. Daily flow values in Cub Run were generated based on the following regression equation.

$$\mathbf{Y = 0.0002\ X^{1.828}}$$

Where:
Y = Cub Run flow (cfs)
X = North River flow (cfs)

Using the above regression and daily flow records at the North River station near Burketown, daily flow values in Cub Run were generated for the period 6/1/26 to 10/29/03.

6.1.2. Flow-Duration Curves

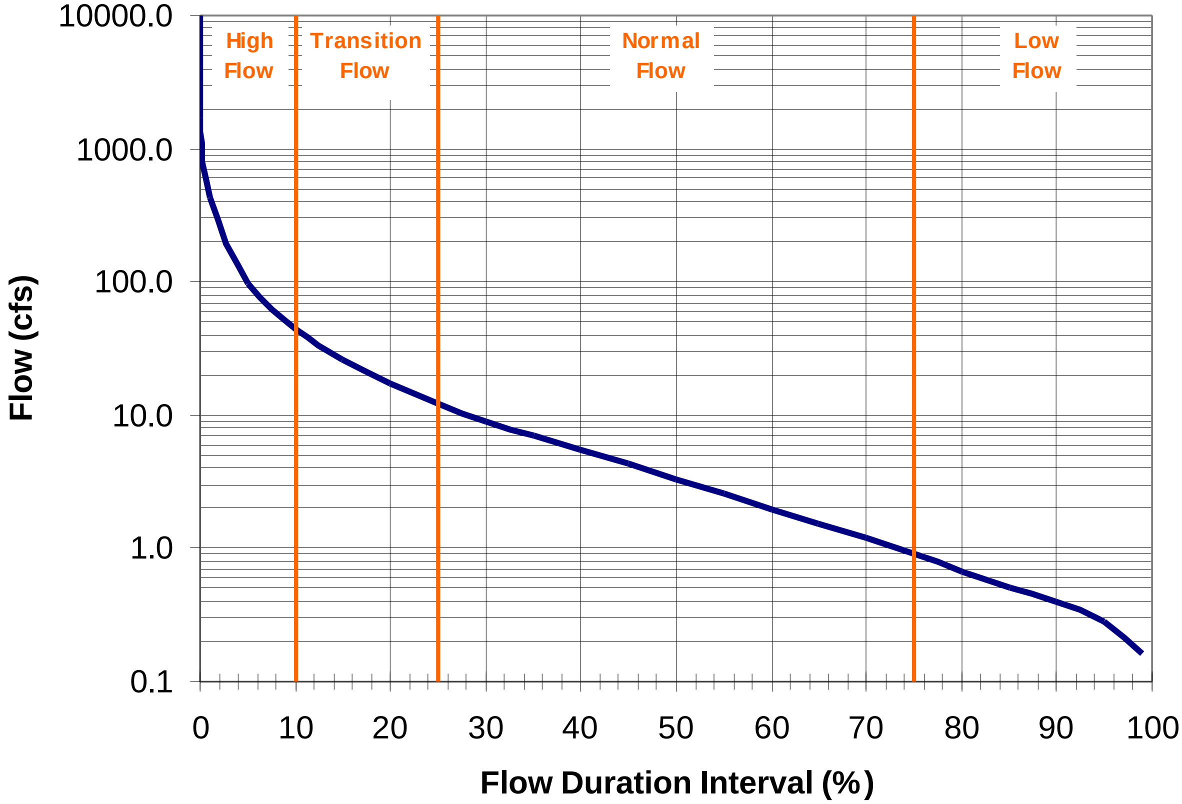
In order to use the load-duration method to develop a TMDL, a flow-duration curve must be developed for the impaired stream. This is accomplished by first developing a flow-duration curve.

A flow-duration curve is a plot showing the flow magnitude (cfs) along the "y" axis and the frequency of daily average stream flow (%) along the "x" axis. For example, the flow value corresponding to “1%” is the flow that has been exceeded only 1% of the time for which measurements exist. Likewise, the flow value corresponding to “30%” is the flow that 30% of the historic record exceeds.

To plot the flow values for the period of record of the reference stream, the PERCENTILE statistic function of Excel was used. The resulting percentile of a given flow was then subtracted from 1 to yield the percent of time that a given flow is exceeded by the flows of record. The flow duration interval values were plotted with the corresponding flows to yield a log/normal flow duration curve. The flow-duration curve for Cub Run is presented in Figure 9.

The flow-duration curve for Cub Run has been divided into four sections to help illustrate flow conditions. These sections are titled "High Flows", "Transition Flows", "Normal Flows", and "Low Flows". Low flows can be roughly equated to near-drought or drought flows. High flows are near-flood or flood flows. Transition flows are, as implied, neither normal nor high.

Figure 9. Flow-duration curve for Cub Run at Rt. 650



6.1.3. Load-Duration Curve

A load-duration curve was developed by multiplying each flow level along the flow-duration curve by the instantaneous *E. coli* standard of 235 cfu/100ml and the required unit conversions. The resulting curve represents the maximum allowable load at each flow level, in other words, the Total Maximum Daily Load (TMDL). The TMDL for Cub Run is shown as the red line on the load-duration curve in Figure 10.

Measured water quality data collected on Cub Run at station 1BCBR000.03 were then added to the load-duration curve to compare the observed loads with the TMDL. *E. coli* was measured in 15 samples from this station from 7/24/02 to 9/15/03. Each water quality observation was plotted based on the *E. coli* load (measured concentration times flow on that day using appropriate unit conversions to cfu/yr) and the flow duration interval for that day's flow. Measured water quality data are shown as blue points on the load-duration curve in Figure 10. Points above the red TMDL line are water quality samples that exceed the water quality standard, and points below the line are samples that meet the water quality standards and the TMDL.

Figure 10. Load duration curve and observed data for Cub Run at station 1BCBR000.03

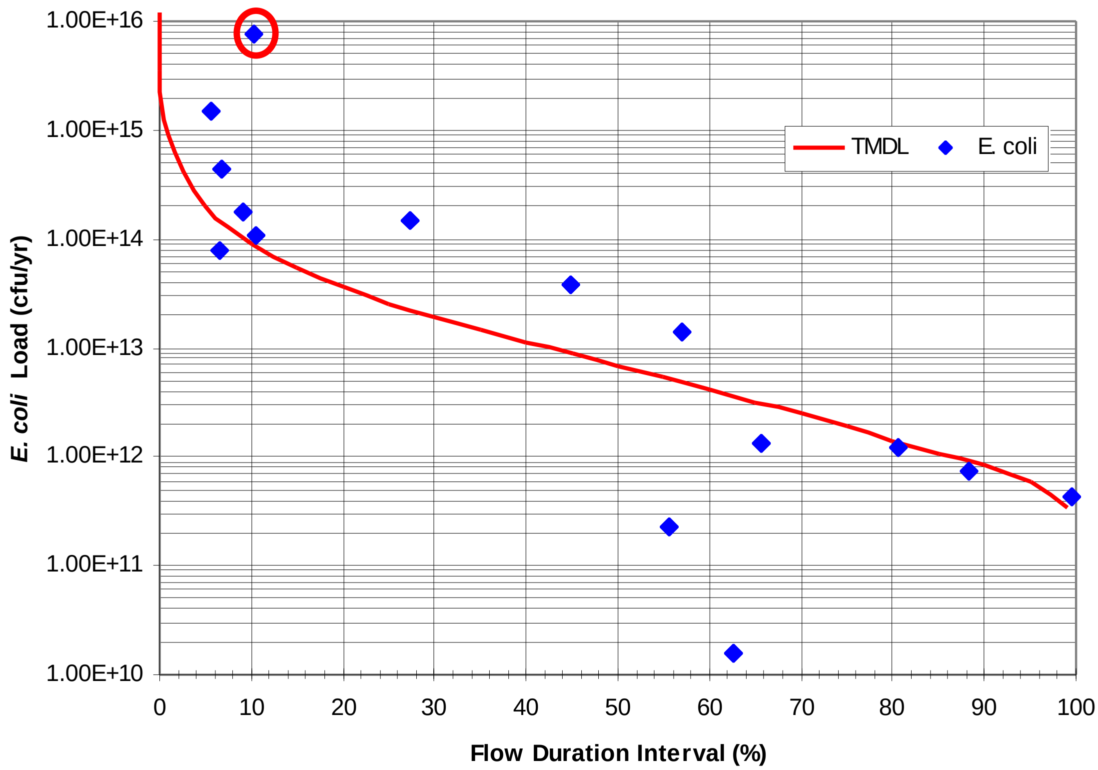
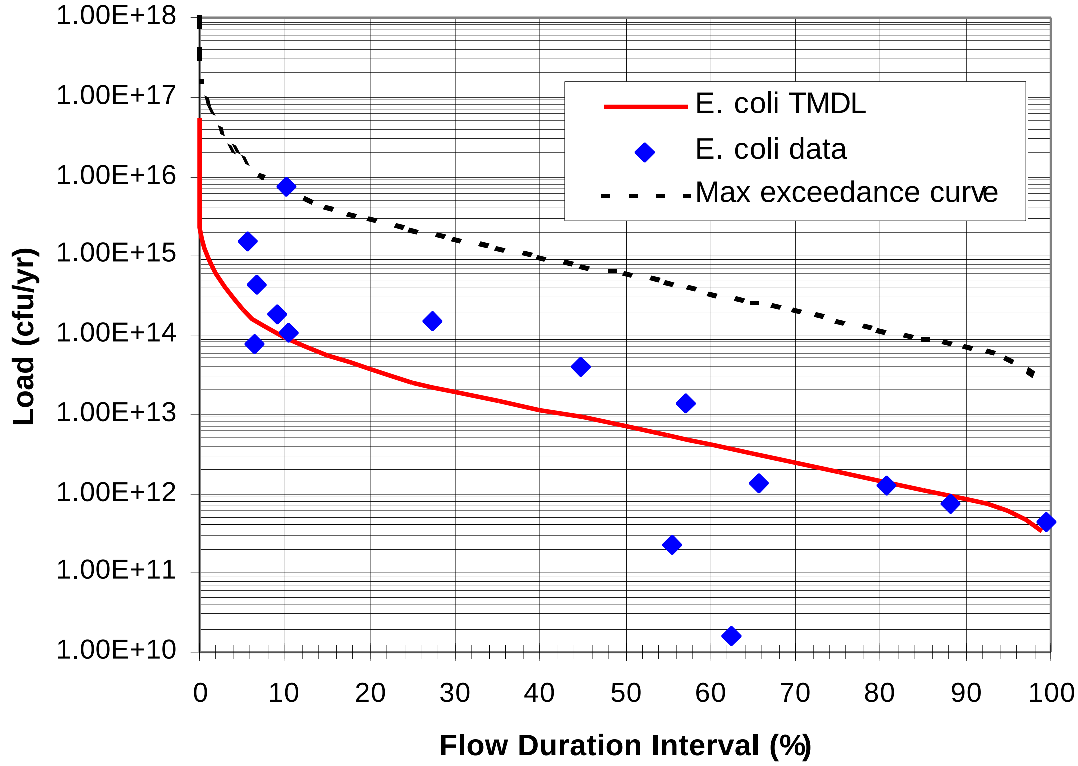


Figure 10 suggests that exceedances of the water quality standard typically occur under higher flow conditions. For samples collected at higher than median flow (below 50% on the flow-duration curve), 88% (all but one) exceeded the water quality standard. For samples collected at flows below the median (above 50% on the flow-duration curve), 29% (only two) exceeded the water quality standard. These data suggest that exceedences of the bacterial standard in Cub Run are primarily due to non-point source loads associated with runoff events rather than point sources or direct sources such as direct deposit by livestock or wildlife instream. To further investigate the conditions surrounding the observed water quality violations, an analysis of stream flow changes and local precipitation was conducted (see Appendix D). This analysis found that 56% of water quality violations were likely tied to runoff events. Fifty-six percent of the water quality violations occurred on days when the stream flow was increasing and/or when precipitation had fallen on that day or the day before. A slightly lower percentage of water quality violations occurred when stream flow was not rising and when precipitation had not fallen on that day or the day before.

The highest exceedance of the water quality standard (circled) occurs at a high flow that is typically exceeded only 10% of the time (~43 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The *E. coli* load at this flow condition is 7.61×10^{15} cfu/yr. Under the instantaneous *E. coli* standard of 235 cfu/100ml, this load would have to be reduced by 99% to an allowable load of 8.94×10^{13} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions. The full calculation with unit conversions is presented in Appendix C.

In order to determine the necessary load reduction at the average annual flow condition, a second curve must be drawn through the highest exceedance described above. The second curve represents the magnitude of the highest observed exceedance if it were to occur over any flow condition. The graph of the load-duration curve with the max-exceedance curve is presented in Figure 11.

Figure 11. Load duration curve with maximum exceedance curve for Cub Run at station 1BCBR000.03



6.2. TMDL

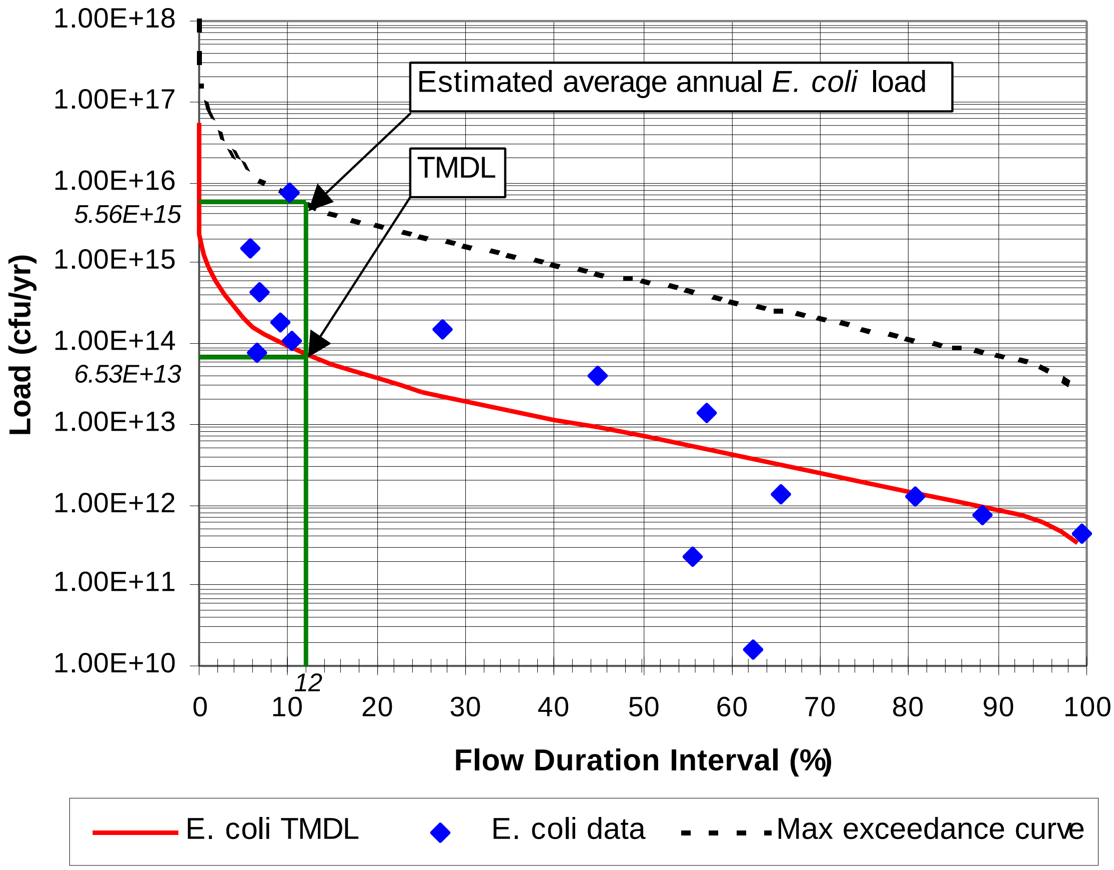
A Total Maximum Daily Load (TMDL) consists of 1) point source waste load allocations (WLAs), 2) non-point source load allocations (LAs) where the non-point sources include natural/background levels, and 3) a margin of safety (MOS) where the margin of safety may be implicitly or explicitly defined. This TMDL definition is typically illustrated by the following equation:

TMDL = WLAs + LAs + MOS

Simply put, a TMDL is the amount of a pollutant that can be present in a waterbody where the waterbody will still meet water quality standards for that pollutant. In the case of load-duration bacteria TMDLs, the TMDL is expressed as the total number of colony forming units (cfu) per year as opposed to cfu/day. This is because the load-duration TMDL must be based on the average annual flow condition.

The average annual flow for Cub Run was estimated as 31.11 cfs from the simulated period of record (see Section 6.1.1). This flow value has an associated flow duration of 12%. From this information, an average annual *E. coli* load and TMDL can be calculated from the maximum exceedance and TMDL curves. This is represented graphically in Figure 12. The full calculation is presented in Appendix C.

Figure 12. Load duration curve illustrating the TMDL and estimated average annual *E. Coli* load for Cub Run at station 1BCBR000.03



The average annual *E. coli* load is 5.56 x 10^{15} cfu/yr, and the TMDL under average annual flow conditions is 6.53 x 10^{13} cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as determined above), the load allocation can be determined. These three values are presented in Table 12.

Table 12. Average annual *E. coli* loads and TMDL for the Cub Run watershed (cfu/yr)

WLA[1]	LA	MOS	TMDL
1.74 x 10^{10}	6.53 x 10^{13}	(implicit)	**6.53 x 10^{13}**

[1] The point sources permitted to discharge in the Cub Run watershed are presented in section 5.2.

7. Allocations

Reduction

The annual average TMDL and *E. coli* load values from section 6.2, together with the waste load allocation from the permitted bacteria sources in section 5.2, were plugged into Table 13 to determine the required reduction. Since the required reduction will only apply to the non-point sources, the LA value was used to calculate the required percent reduction. The full calculations are presented in Appendix C.

In the Cub Run watershed, average annual *E. coli* loading must be reduced by 99% to meet the annual average TMDL load of 6.53 x 10^{13}. Based on the load-duration modeling approach, the bacteria water quality standard will be consistently met over the range of flow regimes if the 99% reduction in *E. coli* loading is achieved in the watershed.

Table 13. TMDL and required reduction for Cub Run

Allowable Loads (cfu/yr)		Average Annual *E. coli* Load (cfu/yr)	Required Reduction
Waste Load Allocation (WLA)	1.74 x 10^{10}		
Load Allocation (LA)	6.53 x 10^{13}		
MOS	(implicit)		
TMDL (annual average)	**6.53 x 10^{13}**	**5.56 x 10^{15}**	**99%**

As illustrated in Table 12 and 13, the WLA for the Cub Run watershed has virtually no effect on the LA reduction calculations. The WLA represents less than 1% of the TMDL load.

Margin of Safety

This requirement is intended to add a level of safety to account for any inherent uncertainty in the TMDL development process and the data used in the development. The MOS may be either implicit or explicit. An implicit margin of safety relies on the conservative nature of the assumptions, values, and methods used to calculate a TMDL whereas an explicit margin of safety is a value (typically a percentage) applied at some point during the TMDL calculation.

In the Cub Run TMDL, an implicit MOS was incorporated through the use of conservative analytical assumptions. These include: (1) the use of the single-most extreme water quality violation event which was used to develop maximum exceedance curve over the entire range of flow conditions, and (2) the computation of average annual load using the average flow conditions. Additionally, the load duration method of TMDL development has been evaluated against TMDLs that were developed using computer modeling. The results showed the load duration method to be slightly more conservative.

Allocations

In order to apply the reduction calculated above, the average annual *E. coli* load had to be allocated to each of the four non-point sources identified in the BST analysis. Table 14 shows the distribution of the average annual *E. coli* load among sources, the reduction applied to each source, and the allowable loading for each source.

Table 14. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	Human @ 9.7% (cfu/yr)	Pet @ 20.6% (cfu/yr)	Livestock @ 37.9% (cfu/yr)	Wildlife @ 31.8% (cfu/yr)
Average Annual Load	**5.56 x 10^{15}**	**5.37 x 10^{14}**	**1.14 x 10^{15}**	**2.11 x 10^{15}**	**1.77 x 10^{15}**
Reduction	99%	99%	99%	99%	99%
Allowable Annual Load	**6.53 x 10^{13}**	**6.31 x 10^{12}**	**1.34 x 10^{13}**	**2.47 x 10^{13}**	**2.08 x 10^{13}**

7.1. Consideration of Critical Conditions

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Cub Run is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. The sources of bacteria for Cub Run are a mixture of dry and wet weather driven sources. TMDL development utilizing the load-duration approach applies to the full range of flow conditions. The load-duration approach also applies the highest water quality violation to the entire stream flow record; therefore, the critical conditions for Cub Run were addressed during TMDL development.

7.2. Consideration of Seasonal Variations

Seasonal variations involve changes in stream flow and water quality as a result of hydrologic and climatological patterns. The load-duration approach allows the pattern of water quality exceedances to be examined for seasonal variations. The load-duration method used to develop this TMDL implicitly incorporates the seasonal variations of precipitation and runoff by looking at the highest water quality violation and applying it to the entire stream flow record when calculating the TMDL.

8. Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on Cub Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent “TMDL Implementation Plan Guidance Manual”, published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

8.1. TMDL Implementation Process

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

8.2. Stage I Implementation Goal

As stated in Section 7.0 the TMDL requires a 99% reduction in all non-point source loading in order to attain a 0% violation of water quality standards. DEQ intends to meet water quality goals through an iterative (or staged) implementation process, where implementation steps are taken, monitoring evaluates the progress made, and additional implementation steps are taken until water quality goals are met. Typically, a Stage I implementation goal is set to achieve a 10% violation rate by focussing reductions on just those anthropogenic sources (i.e., not wildlife). Based on the modeling of Cub Run, however, 99% reductions in all anthropogenic sources result in only an overall reduction of 67% and a projected violation rate of 33% (Table 15). Because this scenario would be extremely difficult to meet in the first step of a phased implementation program, a Phase I management scenario was developed to provide more realistic interim goals.

Table 15. Typical Phase I load allocations (based on necessary reductions from anthropogenic sources to meet a 10% violation rate)

	Total (cfu/yr)	Human (cfu/yr)	Pet (cfu/yr)	Livestock (cfu/yr)	Wildlife (cfu/yr)
Average Annual Load	5.56×10^{15}	**5.37×10^{14}**	**1.14×10^{15}**	**2.11×10^{15}**	**1.77×10^{15}**
Reduction	67%	99%	99%	99%	0%
Target Annual Load	1.81×10^{15}	**5.37×10^{12}**	**1.14×10^{13}**	**2.11×10^{13}**	**1.77×10^{15}**
Projected Violation Rate	33%				

In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels and their associated violation rates were assessed. Reduction curves similar to the maximum exceedance/reduction curve of Figure 11 were plotted on the Cub Run load-duration curve. These reduction curves are presented in Figure 13. For each reduction curve, the number of points above that curve represent the theoretical number of water quality violations (estimated based on the observed data) remaining after instituting such reductions. Table 16 shows the theoretical violation rates for a series of varying reductions. A 67% reduction overall corresponds with the typical Phase I scenario of maximum reductions from all anthropogenic sources.

Based on the reduction analysis presented above and consideration of practical, achievable goals for Phase I implementation, a Phase I management scenario of 50% overall reductions was selected (Table 17). This Phase I management scenario provides realistic first stage goals, and produces a projected violation rate that is only slightly higher than the violation rate projected from a Phase I scenario requiring maximum reductions from all anthropogenic sources. Due to the uncertainty related to stream water quality modeling and conservative estimates used in the modeling approach, the Phase I management scenario may achieve much higher compliance with the standard than projected. Phasing the implementation with realistic steps allows monitoring to verify the point at which implementation has successfully achieved water quality standards.

Figure 13. Load duration curve illustrating the TMDL and reduction curves for Cub Run at station 1BCBR000.03

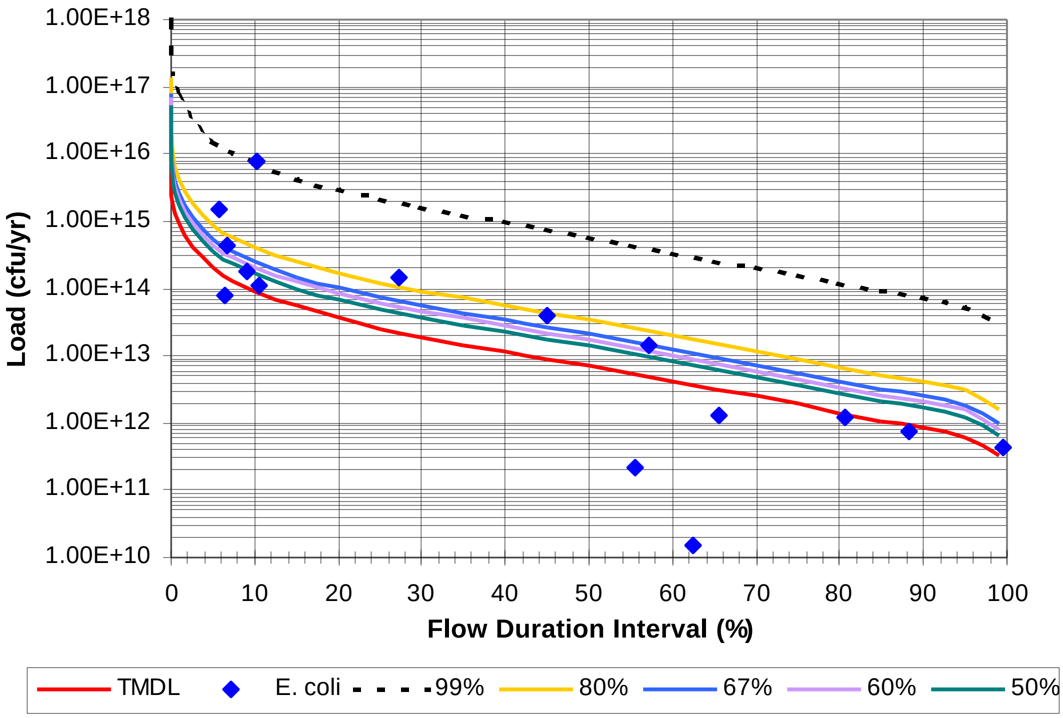


Table 16. Load reductions and water quality standard violation rates

Load Reduction	Violation Rate
99%	0%
90%	7%
80%	20%
67%	33%
60%	40%
50%	40%
Current Load	60%

Table 17. Phase I management scenario (based on a 50% reduction)

	Total (cfu/yr)	Human (cfu/yr)	Pet (cfu/yr)	Livestock (cfu/yr)	Wildlife (cfu/yr)
Average Annual Load	5.56×10^{15}	$\mathbf{5.37 \times 10^{14}}$	$\mathbf{1.14 \times 10^{15}}$	$\mathbf{2.11 \times 10^{15}}$	$\mathbf{1.77 \times 10^{15}}$
Reduction	50%	90	70	70	0
Target Annual Load	2.80×10^{15}	$\mathbf{5.37 \times 10^{13}}$	$\mathbf{3.43 \times 10^{14}}$	$\mathbf{6.32 \times 10^{14}}$	$\mathbf{1.77 \times 10^{15}}$
Projected Violation Rate	40%				

Based on the flow duration curve and an analysis of precipitation in the watershed, the majority of observed water quality violations appear to be linked to runoff from the land surface (see Section 6.1.3 and Appendix D). This information can be useful in targeting possible BMPs in the watershed. BMPs effective in reducing bacteria runoff from precipitation events include: riparian buffers zone, nutrient management, retention ponds/basins, range and pasture management, and animal waste management. BMPs effective in correcting dry weather/low-flow violations of the bacteria water quality standard typically include: streamside fencing for cattle exclusion, straight pipe replacement, and septic system repair. Detailed lists of BMPs and their relative effectiveness will be presented in the eventual TMDL implementation plan for the Cub Run watershed.

8.3. Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the 2001 Interim Nutrient Cap Strategy for the Shenandoah/Potomac basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (2001 Draft Interim Nutrient Cap Strategy for the Shenandoah/Potomac River Basins). A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information can be found at the

tributary strategy web site under
http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

8.4. Reasonable Assurance for Implementation

8.4.1. Follow-Up Monitoring

VADEQ will continue to monitor Cub Run in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from the monitoring station on Cub Run to evaluate reductions in bacteria counts and the effectiveness of the TMDL in attainment of water quality standards. Ambient sampling includes field parameters (temperature, pH, dissolved oxygen, conductivity), bacteria, nutrients and solids. Future bacteria sampling will consist of *E. coli* sampling only, since the interim fecal coliform bacteria will be phased out after twelve *E. coli* samples have been collected.

8.4.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

8.4.3. Implementation Funding Sources

A key factor in implementing TMDLs is funding. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Watershed restoration activities, such as TMDL implementation, are eligible for Section 319 funding. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentive Programs (EQIP), the Virginia State Revolving Loan Program, and the VA Water Quality Improvement Fund (WQIP). The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

8.4.4. Wildlife Contributions and Water Quality Standards

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria will become effective pending EPA approval and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 8.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

9.0 Public Participation

Public involvement in the development and implementation of TMDLs is essential. A public meeting was held in McGaheysville, Virginia on February 12, 2003 to discuss the process for TMDL development and the source assessment input. Approximately 34 people attended. Copies of the presentation materials and the draft TMDL report were available for public distribution. The meeting was public noticed in the Virginia Register. There was a 30 day-public comment period and one set of written comments was received. These comments were responded to in a letter to the commenter. Comments and responses are being submitted to EPA under separate cover.

10. References

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Appendix A

Glossary

GLOSSARY

Note: All entries in italics are taken from USEPA (1998). All non-italicized entries are taken from MapTech (2002).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established* *under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the* *receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Non-point source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Phased approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Raw sewage. *Untreated municipal sewage.*

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100ml geometric mean limit).

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

DACS. Department of Agriculture and Consumer Services.

DCR. Department of Conservation and Recreation.

DEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also* ***Domestic wastewater****.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

Appendix B

Antibiotic Resistance Analysis

(MapTech)

When performing ARA, isolates (colonies picked from membrane filtration plates) of *E. coli* or *Enterococcus* are transferred to a 96-well tissue culture plate (one isolate per well) containing a selective liquid medium. The 96-well plates are incubated and confirmed as *E. coli* or *Enterococcus* by color changes in the liquid after incubation (Figure A-1). Antibiotic stock solutions are prepared and each of twentyeight or more antibiotic/concentrations is added separately to flasks of autoclaved and cooled Trypticase Soy Agar (TSA) from the stock solutions to achieve the desired concentration, and then poured into sterile 15x100mm petri dishes.

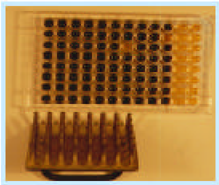

Figure A-1. 96-well plate after incubation.

Control plates (no antibiotics) are included with each set. Isolates are transferred from the 96-well plate using a stainless steel 48-prong replica plater (Sigma). The replicator is flame-sterilized (95% ethanol) after inoculation of each TSA plate. Resistance to an antibiotic is determined by comparing each isolate to the growth of that isolate on the control plate. A one (1) is recorded for growth and a zero (0) is recorded for no growth (Figure A-2). This is repeated for each isolate on each of the 30 antibiotic plates to develop a profile.

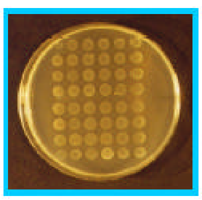

Figure A-2. TSA control plate (with no antibiotics) showing growth of all 48 isolates.

The profile is then compared against the known source library to determine the source of the isolate (see data analysis section). The basic process is the same for all approaches, that is, a data base of known sources analyzed using the BST method of choice must be developed and samples of unknown bacterial origin are collected, analyzed and compared to the known source database. For studies, such as Total Maximum Daily Loads (TMDL), we recommend the ARA procedure due to typical cost constraints. Typically we analyze 24 isolates per unknown source (e.g. stream or well water) sample. This provides measurements of the proportion of a given source that are in increments of approximately 4%. If more precision is required, 48 isolates can be analyzed, resulting in resolution of approximately 2%. If the sampling is to be done in a geographical area where a database of known sources has not been developed, we will need to collect samples from known sources (i.e. human, livestock, wildlife) and compare them to our existing databases to determine if one of our existing databases is compatible with the study area. Twenty-four isolates from each of these samples will be analyzed. If no existing database is compatible, we will need to develop a database for the study area. The number of samples needed depend on variability of source samples. We have had a good deal of success in the past by using existing databases through obtaining known source samples from each group (i.e. human, livestock, wildlife) in the study area and comparing them to existing databases.

Appendix C

Calculations

Calculations

Waste Load Allocation Calculation from Section 5.2

WLA cfu/yr = Q mgal/d * 1,000,000 gal/mgal * 3.785 l/gal * 1000 ml/l * 126 cfu/100 ml * 365 d/yr

Where:

WLA cfu/yr = wasteload allocation in cfu/yr
Q mgal/d = design flow in million gallons per day
mgal = million gallons
d = days
gal = gallons
l = liters
ml = mililiters
126 cfu/100 ml = geometric mean *E. coli* standard
cfu = colony forming units
yr = years

Allowable Load Calculation from Section 6.2.

TMDL cfu/yr = Q ft^3/s * 7.48 gal/ft^3 * 3.785 l/gal * 1000 ml/l * 235 cfu/100 ml * 60 s/min * 60 min/day * 24 hrs/day * 365 days/yr

Where:

TMDL cfu/yr = Allowable load in cfu/yr
235 cfu/100 ml = Instantaneous *E. coli* standard
Q ft^3/s = Flow in cubic feet per second
cfu = *E. coli* colony forming units.
l = liters
ml = milliliters
s = seconds
min = minutes
yr = year
gal = gallons

Required Reduction Calculation from Section 7.

TMDL cfu/yr = LA cfu/yr + WLA cfu/yr + MOS (cfu/yr)

OL = LA cfu/yr + WLA cfu/yr

% reduction = [(OL - TMDL)/OL] * 100

Where:

TMDL = total maximum daily load
LA = load allocation
WLA = waste load allocation
MOS = margin of safety
OL = observed load (average annual load)

Appendix D

Flow Change and Precipitation Analysis

In the interest of better-targeted BMPs for the Cub Run watershed, the correlation between water quality violations, stream flow changes and precipitation was investigated. The goal was to determine which violations might be related to runoff and which might be related to direct deposition.

As stated in Section 6.1, flow data for Cub Run were simulated from flow records on the North River near Burketown. Precipitation data were obtained from a weather station within the watershed in Keezletown, Virginia (The Weather Underground, Inc., 2003). Flow data were examined to determine if stream flows were increasing on the day of the water quality violation. Precipitation data were examined to determine if precipitation fell on the day of the water quality violation or on the day prior to the violation. Results of this investigation are shown in the Figure and Table below.

Figure D-1. Precipitation and Flow Annotated WQS Violation Events (Cub Run Watershed)

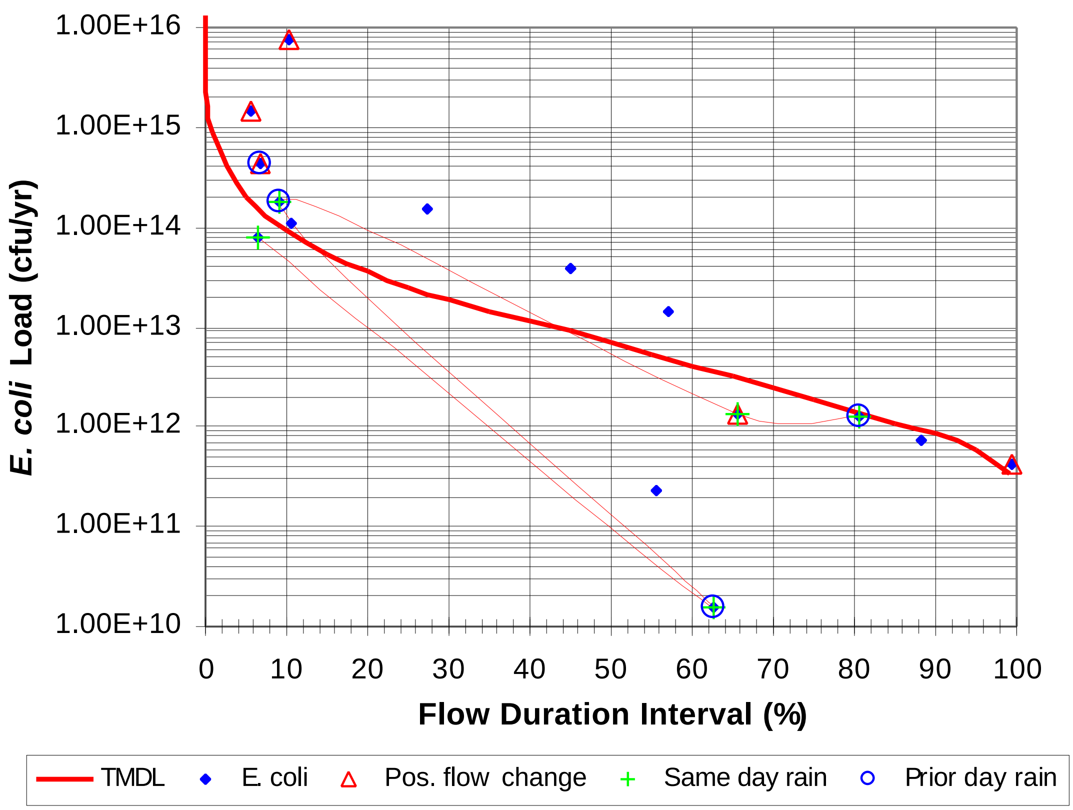

Table D-1. Water Quality Standard Violations, Stream Flow Change, and Precipitation

Sampling Date	Fecal Coliform (cfu/100ml)	*E. coli* Value (cfu/100ml)	Duration Interval	*E. coli* Load (cfu/yr)	Increasing Flow	Same Day Rain (inches)	Prior Day Rain (inches)
7/24/02	100	210	80.7	1.24E+12	no	0.02	0.64
8/7/02	150	190	88.3	7.39E+11	no	0	0
9/9/02	600	330	99.5	4.34E+11	yes	0	0
10/28/02	250	100	65.6	1.33E+12	yes	0.03	0
11/19/02	410	400	9.1	1.77E+14	no	0.04	0.02
12/17/02	470	300	10.5	1.09E+14	no	0	0
1/28/03	30	10	55.5	2.25E+11	no	0	0
2/11/03	10	1	62.5	1.56E+10	no	0.01	0.07
3/11/03	170	120	6.5	7.78E+13	no	0.04	0
4/8/03	4100	2000	5.7	1.5E+15	yes	0	0
5/6/03	800	700	6.8	4.31E+14	yes	no data	0.03
6/30/03	4500	1600	27.3	1.51E+14	no	0	0
7/21/03	2400	1000	44.9	3.86E+13	no	0	0
8/11/03	22000	20000	10.3	7.61E+15	yes	0	0
9/15/03	450	680	57.1	1.4E+13	no	0	0
	Positive flow change						
	Same day precipitation						
	Prior day precipitation						

The results of the investigation suggest that five of the nine water quality violations (56%) could be related to runoff events. These samples were collected on days when stream flows were rising and/or precipitation had fallen. The remaining three water quality violations were identified on days when stream flows were decreasing and rain had not fallen within 24 to 48 hours. Water quality violations under these conditions might indicate direct deposit of fecal matter by wildlife or livestock.

Appendix E

TMDL Scenario with WLA Increased by a Factor of Five

The following tables represent a TMDL scenario where the WLA has been increased by a factor of five. This scenario was presented to the public and is intended to be appended to the originally submitted TMDL report. Since the discharge is meeting water quality standards at the end of pipe, the expanded WLA has virtually no impact on nonpoint source reductions and the expanded WLA is still less than 1% of the entire TMDL. Including this expanded and public-noticed WLA in the TMDL report gives Virginia flexibility to accommodate future expansions and/or additional discharges in an efficient manner.

Table E-1. Average annual *E. coli* loads and TMDL for the Cub Run watershed (cfu/yr)

WLA[1]	**LA**	**MOS**	**TMDL**
8.70×10^{10}	6.52×10^{13}	(implicit)	**6.53×10^{13}**

[1] The point source permitted to discharge in the Cub Run watershed are presented in section 5.2.

Table E-2. TMDL and required reduction for Cub Run

Allowable Loads (cfu/yr)		**Average Annual *E. coli* Load (cfu/yr)**	**Required Reduction**
Waste Load Allocation (WLA)	8.70×10^{10}		
Load Allocation (LA)	6.52×10^{13}		
MOS	(implicit)		
TMDL (annual average)	**6.53×10^{13}**	**5.56×10^{15}**	**99%**

Table E-3. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	**Human @ 9.7% (cfu/yr)**	**Pet @ 20.6% (cfu/yr)**	**Livestock @ 37.9% (cfu/yr)**	**Wildlife @ 31.8% (cfu/yr)**
Average Annual Load	**5.56×10^{15}**	**5.37×10^{14}**	**1.14×10^{15}**	**2.11×10^{15}**	**1.77×10^{15}**
Reduction	99%	99%	99%	99%	99%
Allowable Annual Load	**6.52×10^{13}**	**6.30×10^{12}**	**1.34×10^{13}**	**2.47×10^{13}**	**2.08×10^{13}**